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WATER RESOURCES
REPORT 5c

The Hydrogeology of the IFYGL Duffins Creek Study Area

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PREFACE

Part of the contribution of the Ontario Ministry of the Environment to the International Field Year for the Great Lakes (IFYGL) program was the estimation of ground-water inflow to Lake Ontario from the Canadian side, by extrapolating data from selected areas representative of larger hydrogeologic regions. This report, which describes the hydrogeology of the IFYGL Duffins Creek study area, is one in a series of several reports dealing with the ground-water regimes of seven, selected representative areas along the Canadian shore of Lake Ontario.

Toronto, May, 1979

G.H. Mills, Director
Water Resources Branch

CONTENTS

	Page
ABSTRACT	ix
INTRODUCTION	1
PURPOSE AND SCOPE	1
LOCATION	1
ACKNOWLEDGEMENTS	1
GEOGRAPHY	3
PHYSIOGRAPHY	3
CLIMATE	4
GEOLOGY	6
BEDROCK GEOLOGY	6
PLEISTOCENE GEOLOGY	7
Introduction	7
Stratigraphy and History	7
HYDROGEOLOGY	15
GROUND-WATER OCCURRENCE	15
GROUND-WATER LEVELS	16
GROUND-WATER MOVEMENT	18
Ground-Water Flow Field	18
Water-Level Data	21
Potentiometric Surface	21
Hydraulic Gradient	22
AQUIFER CHARACTERISTICS	24
Introduction	24
Well Yields	25
Transmissibility (modified non-equilibrium well formula)	27
Transmissibility (specific capacity)	28
GROUND-WATER CONTRIBUTION TO LAKE ONTARIO	32
Introduction	32
Contributing Area	32
Depth of Active Flow	32
Saturated Thickness	33
Transmissibility	33
Hydraulic Gradient	33
Computation of Ground-Water Inflow	33
Additional Ground-Water Inflow	34
SUMMARY AND CONCLUSIONS	35
SELECTED BIBLIOGRAPHY	37

FIGURES

Figure		Page
1.	Location of the IFYGL Duffins Creek study area in southern Ontario......................	x
2.	Hydrograph comparison of Lake Ontario and observation wells at site P1-A in the IFYGL Duffins Creek study area......................	19
3.	Observation-well hydrographs for wells 301, 302 and 303 in the vicinity of the IFYGL Duffins Creek study area......................	20
4.	Specific-capacity frequency graphs for bedrock and overburden wells in the IFYGL Duffins Creek study area..................................	26
5.	Theoretical relationship between specific capacity and the coefficient of transmissibility (after Csallany et al, 1963)..........	30

TABLES

Table		Page
1.	Normal monthly precipitation and temperature data at the Pickering-Audley meteorologic station (from Environment Canada, Atmospheric Environment Services,1971)...................	5
2.	Pleistocene stratigraphy in the Toronto to Bowmanville areas............................	8
3.	Comparison of the Meadowcliffe and Sunnybrook tills (Karrow, 1967)..........................	11
4.	Carbonate analyses of the Leaside till.........	12
5.	Static levels and change in water levels of the observation-well network in the IFYGL Duffins Creek study area......................	17
6.	Average annual precipitation in the IFYGL Duffins Creek study area......................	18
7.	Computed, vertical head gradients in piezometer nests P1-A, P1-B and P-2 on May 2, 1972, November 6, 1972, and March 29, 1973..........	23
8.	Permeabilities of the materials in the IFYGL Duffins Creek study area......................	28
9.	Comparison of permeabilities derived from specific-capacity and pumping-test data of the same wells in the IFYGL Duffins Creek study area	31
10.	Mean values of transmissibility, static water-level depth, overburden thickness and bedrock penetration for wells completed within one mile of the Lake Ontario shore in the IFYGL Duffins Creek study area............................	34

MAPS
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Map

1. Physiographic regions.
1a. Meteorologic stations and observation wells.
2. Bedrock geology and topography.
3. Locations of water wells.
4. Surficial geology and overburden thickness.
5. Wisconsinan age strand lines.
6. Permeable deposits at elevations 230-245, 322-335, and 408-425.
7. Permeable deposits at elevations 245-260, 335-347, and 386-404.
8. Permeable deposits at elevations 260-279, 298-325, and 368-385.
9. Permeable deposits at elevations 280-301, and 348-370.
10. Generalized potentiometric surface.

ENGLISH - METRIC (SI) FACTORS

to convert	to	multiply by
inches (in)	centimetres (cm)	2.540
feet (ft)	metres (m)	0.305
miles (mi)	kilometres (km)	1.609
square miles (mi^2)	square kilometres (km^2)	2.590
cubic feet/second (cfs)	litres/second (l/s)	28.316
Imperial gallons (Ig)	litres (l)	4.546
Imperial gallons/day (Igpd)	litres/second (l/s)	5.262×10^{-5}
Imperial gallons/day/ft^2 (Igpd/ft^2)	metres/second (m/s)	5.663×10^{-7}
Imperial gallons/day/ft (Igpd/ft)	square metres/second (m^2/s)	1.726×10^{-7}
Imperial gallons/min (Igpm)	litres/sec (l/s)	.0758

ABSTRACT

The assessment of the ground-water contribution to Lake Ontario from the hydrogeologic region along the north shore of the lake, extending from the Humber River near the western limits of the City of Toronto to the City of Oshawa, was undertaken by the Ontario Ministry of the Environment as part of its contribution to the International Field Year for the Great Lakes (IFYGL) program. Data were extrapolated from the hydrogeologic evaluation of the lower part of the Duffins Creek drainage basin which was considered to be representative of the ground-water regime in this hydrogeologic region.

Field investigations of the geology, test drilling, data from water-well records on file with the Ministry and published literature were utilized for the assessment of the hydrogeology.

Ground-water supplies in the study area are obtained from the upper part of the Upper Ordovician shales and the overlying Wisconsinan drift. High-level, glacial lake deposits of permeable materials that are being utilized for ground water in the study area were tentatively identified as being part of the Thorncliffe Formation. Water-wells completed in the overburden are more productive than wells completed in the bedrock, with overburden wells having a specific-capacity range of 0.8 to 5.0 Igpm per foot of drawdown.

An excess of 4.29 inches of precipitation over the long-term annual average during the IFYGL period (April 1, 1972 to March 31, 1973) resulted in an increase in storage of 0.85 feet in the ground-water reservoir of the study area.

Permeability values, derived from short-term pumping tests, were assigned to the various materials in the study area. From these values it was estimated that five cfs of ground water is discharging directly into Lake Ontario along the shore of the hydrogeologic region.

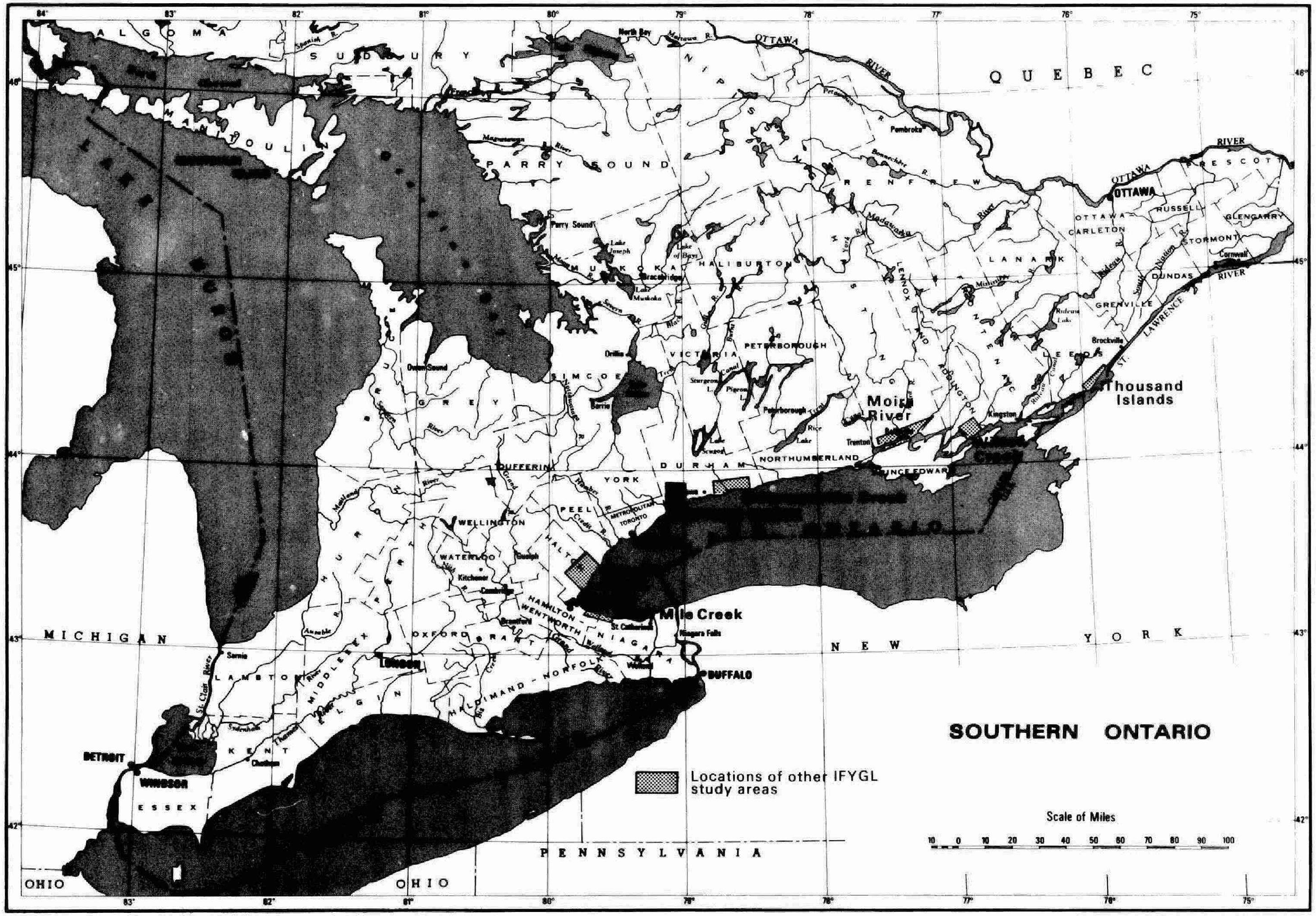

Figure 1. Location of the IFYGL Duffins Creek study area in southern Ontario.

INTRODUCTION

PURPOSE & SCOPE

Under the sponsorship of the Canadian and U.S. National committees for the International Hydrological Decade (IHD) program, the International Field Year for the Great Lakes program (IFYGL) was established. The purpose of the IFYGL was to study, in detail, the various hydrologic aspects associated with Lake Ontario and its drainage basin. Part of the Ontario Ministry of the Environment's contribution to the IFYGL program was the study of ground-water inflow to Lake Ontario, by extrapolating data from selected areas representative of larger hydrogeologic regions.

The ground-water regime developed in any region is a result of the geology, topography, drainage and climate of that area. In the hydrogeologic region along the north shore of Lake Ontario, from the Humber River near the western limits of the City of Toronto to the City of Oshawa (Figure 1.), ground-water conditions are considered to be uniform. The Duffins Creek drainage basin is situated in this area and was selected for the IFYGL study as a result of hydrogeological investigations being conducted by the Ministry in the basin. These investigations are part of an ongoing program for the assessment of water resources in the Province of Ontario.

For the purposes of the IFYGL study, to determine the amount of ground-water inflow to Lake Ontario, only the area adjacent to the Lake was studied. Field investigations were made of the geology and test drilling was conducted to provide information on aquifer characteristics, subsurface geology and ground-water levels in the area. Other aspects of the hydrogeologic assessment utilized information obtained from published literature and water-well records filed with the Ministry of the Environment.

LOCATION

The study area is situated in the Regional Municipality of Durham, formerly the Township of Pickering in the County of Ontario, between longitudes 78° 58' 15" W and 79° 06' 00"W on the north shore of Lake Ontario. At the north end, the area is bounded by latitude 43° 54' 30" N. Duffins Creek enters the north part of the study area at longitude 79° 04' 08" W and flows through the western part of the Town of Ajax into the Lake at longitude 79° 02' 08" W (Figure 1).

ACKNOWLEDGEMENTS

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The author wishes to acknowledge the co-operation of the Ontario Hydro-Electric Power Commission for making their geotechnical data available on the Pickering Generating Station and also the co-operation of the Ontario Ministry of Transportation and Communications for the use of data contained in foundation investigation reports prepared for that Ministry.

The Metropolitan Toronto and Region Conservation Authority and the County of Ontario granted permission to install observation wells on Conservation Authority property and on County road allowances.

Appreciation is expressed to the residents of the area for their co-operation during the study period.

GEOGRAPHY

PHYSIOGRAPHY

Two major physiographic regions, the Iroquois Plain and the South Slope as delineated by Chapman and Putnam (1966), are found in the study area (Map 1). All but the northwest corner of the study area is considered to be part of the Iroquois Plain. This plain has been defined by Chapman and Putnam as the lowland that borders Lake Ontario which was inundated in late Pleistocene times by glacial Lake Iroquois. In the study area, the lake bottom is ground moraine which was smoothed by wave action and the deposition of lacustrine sediments in depressions within the inundated area. The most prominent feature in the region is the northeast-trending bluff of the Iroquois shoreline (Map 1), separating the Iroquois Plain in the south from the drumlinized till plain of the South Slope region to the northwest.

A maximum relief of approximately 450 feet is present from Lake Ontario at ± 245 feet above sea level (asl) to the highest spot elevation in the northwest corner of the study area at approximately 700 feet asl. A regional topographic gradient of approximately 25 feet per mile, extending inland from the Lake Ontario shore and increasing northwards, is present in the bulk of the area. This is the offshore facies of glacial Lake Iroquois where silt and clay deposits are found in the depressions of the inundated and wave-modified ground moraine. In the western part of the study area, in the vicinity of Frenchman's Bay, the regional topographic gradient increases to 75 feet per mile to the northwest.

In the nearshore facies of Lake Iroquois, the regional topographic gradient increases in the order of 100 feet per mile to the northwest. This area is delineated by boulder pavements and beach and bar deposits extending one to one and a half miles south of the Iroquois shoreline. In the drumlinized till plain of the South Slope physiographic region, north of the old shoreline, the regional topographic gradient increases to the northwest at approximately 150 feet per mile.

Minor streams in the southwest corner and far eastern part of the study area drain directly into Lake Ontario. The remaining and major part of the area is drained by the lower reaches of Duffins Creek and its tributaries. The Duffins Creek watershed is drained by two major creeks, the East and West branches. Their confluence is about three and one-half miles north of Lake Ontario near the northwest limits of the Town of Pickering, in the central part of the study area (Map 1). The East Branch enters the study area in the north and flows southward, with an average fall of 30 feet per mile, for approximately four miles to its junction with the West Branch. The latter enters the area from the west, flowing eastward for three miles, with an average drop of 40 feet per mile. A reduced gradient of less than 20 feet per mile occurs in the streambed from the union of the branches to the creek's mouth at Lake Ontario. This reduced gradient, in the lower reaches of Duffins Creek, is in part a result of differential uplift causing partial drowning of the creek mouth.

CLIMATE

The climate of the study area is influenced by the presence of Lake Ontario. Most of the study area is in the climatic region of the "Lake Ontario Shore", as classified by the Ontario Department of Agriculture and Food (1966). A small portion, in the north and northwest of the area, falls into the climatic region of the "South Slopes".

Three precipitation stations, Frenchman's Bay, Pickering, Greenwood MTRCA and one meteorological station, Pickering-Audley, were in operation within the vicinity of the study area (Map 1a). The meteorological data at the Pickering-Audley station were assumed to indicate the climate in the area. The long-term annual precipitation (11 years record) at this station is 31.91 inches and the normal long-term annual temperature is 44.0°F. The normal monthly precipitation and temperature values for the Pickering-Audley station are shown in Table 1. These long-term data are not available for the Frenchman's Bay, Pickering and Greenwood MTRCA stations.

TABLE 1. NORMAL MONTHLY PRECIPITATION AND TEMPERATURE DATA AT THE PICKERING-AUDLEY METEOROLOGIC STATION (from Environment Canada, Atmospheric Environment Services, 1971).

	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (inches)													
Mean Rain	26.44	0.97	0.87	1.82	2.46	2.87	2.51	2.84	2.90	2.63	2.69	2.27	1.61
Mean Snow*	5.47	1.28	1.39	1.01	0.18	-	-	-	-	-	0.05	0.45	1.11
Mean Total	31.91	2.25	2.26	2.83	2.64	2.87	2.51	2.84	2.90	2.63	2.74	2.72	2.72
Temperature (°F)													
Mean Daily	44.0	19.6	20.4	28.8	42.3	52.3	62.2	66.9	66.0	59.1	48.0	37.4	24.6
Mean Daily Max	53.3	26.8	28.5	36.7	51.9	62.8	73.5	78.2	77.2	69.7	58.2	44.7	31.5
Mean Daily Min	34.6	12.3	12.3	20.8	32.6	41.7	50.9	55.6	54.7	48.4	37.7	30.0	17.6

* water equivalent

GEOLOGY

BEDROCK GEOLOGY

The study area is underlain by shales from the lower part of the Upper Ordovician time scale. These shales are part of the middle member of the Whitby Formation (Liberty, 1969) formerly known as the Blue Mountain, Gloucester and Collingwood formations. The middle member is comprised of thin-bedded, brown, bituminous, micaceous, slightly calcareous shale which contains minor amounts of black, blue and dark carbonaceous shale. According to Liberty (1969), these deposits are indicative of slow sedimentation in quite, shallow waters which is further supported by field evidence of ripple marks and abundant mud-cracked surfaces.

The structure of the bedrock is obscured by a veneer of glacial drift in the study area. The bedrock is relatively flat-lying and dips to the south-southwest at approximately 20 to 30 feet per mile (Liberty, 1969).

The elevation of the bedrock surface is illustrated in Map 2. The attitude of this surface was compiled from records of water wells (on file with the Ministry of the Environment) that penetrate the overburden to the bedrock; borehole data obtained for the foundation investigation of the Pickering Generating Station (The Hydro-Electric Power Commission of Ontario, 1965); and foundation reports for provincial highways in the study area (Ontario Ministry of Transportation & Communications 1959, 1967, 1969 and 1970). The location of these data points are shown in Map 3. The data suggest that the bedrock surface rises gently northwards with an average gradient of 25 feet per mile, similar to that of the ground surface. The average elevation of the bedrock surface at the Lake Ontario shore is approximately 200 feet asl (50 feet below lake level) and 350 feet asl (25 to 100 feet below the ground surface) in the north end of the study area. The maximum recorded relief is in the order of 200 feet, approximately one half that of the topographic surface, from 145 feet asl near Lake Ontario at the Town of Ajax to 350 feet asl at the north end of the study area.

Two major bedrock valleys which drained to the south have been identified in the study area (Map 2). The East Branch of the Duffins Creek occupies the same general area as the largest bedrock valley. Information to date suggests that the mouth of Duffins Creek at Lake Ontario is approximately two miles west of this ancient valley. The other bedrock valley was occupied by an ancient stream that drained into the present-day Frenchman's Bay area from the northwest.

PLEISTOCENE GEOLOGY

Introduction

The record of geological history from the Ordovician to the Quaternary periods is missing in the southcentral part of Ontario. The unconsolidated materials overlying the bedrock in the study area were deposited during the Pleistocene or Glacial Epoch and are generally considered to be Wisconsinan in age. Investigations of the glacial deposits have been made by earlier workers, notably Coleman (1936), Caley et al (1947), Olding et al (1956), Gravenor (1959), Chapman and Putnam (1966) and Hewitt (1969).

The deposits in the study area are described as glacial, glaciofluvial and glaciolacustrine in origin; with thicknesses ranging from a few feet to more than 150 feet (Map 4). In general, low areas in the bedrock surface, such as ancient stream valleys cut into the bedrock (Map 2), have been filled with glacial debris; whereas bedrock highs (east and west of Duffins Creek near the shore of Lake Ontario) are covered with a relatively thin cap of glacial material. It would appear that the net result of glaciation in the study area was to smooth the pre-existing bedrock surface. A paucity of data on the bedrock surface in the northwest part of the study area does not allow for accurate delineation of the thickness of the overburden deposits there.

Stratigraphy and History

Stratigraphy .... The most recent work on the Pleistocene stratigraphy, to the west and east of the study area, has been completed by Karrow (1967) and Singer (1973), respectively (Table 2). For the most part, only the deposits of the Fourth (most recent) Pleistocene glaciation, the Wisconsinan Stage, are present in this part of Ontario. Some exposures of Illinoian Till from the Third Pleistocene glaciation and interglacial deposits of the Sangamonian Stage have been identified in the Toronto area to the west of the study area. These deposits have not been identified east of Toronto.

Early Wisconsinan and Older .... To date, deposits older than the Middle Wisconsinan have not been identified in surface exposures within the study area. Subsurface information, obtained from water-well records on file with the Ministry, suggests that the Scarborough Formation and Sunnybrook Till of Early Wisconsinan age may be present in the western part of the area. Positive correlation of these deposits has not been successful to the present time.

TABLE 2. PLEISTOCENE STRATIGRAPHY IN THE TORONTO TO BOWMANVILLE AREAS

Period	Epoch	Stage	Substage	Stade	Toronto Area (After Dreimanis & Karrow 1972)	Duffins Area	Bowmanville Area (After Singer, 1973
Quaternary	Pleistocene	Wisconsinan	Late		L. Iroquois deposits	L. Iroquois deposits	Proglacial Unit
				Port Huron Stadial Mackinaw Interstadial	U. Leaside Till	U. Leaside Till	U. Glacial Unit
				Nissouri Stadial	L. Leaside Till	L. Leaside Till	
			Middle	Plum Point Interstadial	U. Thorncliffe Lake beds	Late Lake phase	not identified
				Cherrytree Stadial	Meadowcliffe Till	Meadowcliffe Till	M. Glacial Unit
				Port Talbot Interstadial	L. Thorncliffe Lake beds Seminary Till L. Thorncliffe Lake beds	Intermediate Lake phase Seminary Till Early Lake phase	Clarke Deposits
			Early	Guildwood Stadial St. Pierre Interstadial	Sunnybrook Till	Sunnybrook Till	L. Glacial Unit
				Nicolet Stadial	Scarborough Formation	not identified	not identified
		Sangamonian			Don Formation		
		Illinoian			York Till		
Ordovician	Cincinnatian	Edenian	Gloucesterian	Nottawasaga Group		Whitby Formation	

The type section of the Scarborough Formation, as exposed in the Scarborough Bluffs, consists of a lower clay unit averaging 90 feet of exposure above the present lake level and an upper sand unit averaging 50 feet in thickness (Karrow, 1967). Subsurface deposits west of Frenchman's Bay and east of the Town of Ajax may be correlative with the Scarborough Formation.

In the Toronto area, the Sunnybrook Till has been established as a major till sheet extending under most of the area (Karrow, 1967). According to Karrow, the Sunnybrook Till is a fine-grained till varying from a silt till to a silty clay till with a low pebble content. The thickness of the till is variable and is most often found to be 20 to 30 feet thick in the Scarborough Bluffs. Data from water-well records suggest that the Sunnybrook Till is present at depth throughout most of the study area. To the east, a basal till with similar characteristics has been identified by Singer (1973) in the Bowmanville area and correlated with the Sunnybrook Till.

According to Karrow (1967), the sediments of the Scarborough Formation are considered to be part of a delta formed in the Scarborough area at the mouth of a large southward-flowing river. This river emptied into a proglacial lake (Lake Scarborough) that occupied the Lake Ontario basin when the earliest Wisconsinan glacier reached the eastern end of present-day Lake Ontario from the north. The ice dammed up the St. Lawrence valley raising the water level while drainage was diverted down the Mohawk and Hudson valleys to the sea. The ice front then retreated allowing the lake level to fall during which time the Scarborough delta was dissected by streams. A cooling of the climate brought about a major ice advance which completely covered the area and deposited the Sunnybrook Till. The ice at this time flowed into the Lake Ontario basin and spread westward over the Scarborough delta. The texture of this till is indicative of the fine-grained lacustrine material that was incorporated during the advance over the Lake Scarborough deposits in the Lake Ontario basin.

<u>Thorncliffe Formation ...</u> Karrow (1967) has named the variety of glacial, fluvial and lacustrine deposits found between the earliest Wisconsinan till, the Sunnybrook, and the latest till, the Leaside, the Thorncliffe Formation. In Karrow's type section on the Scarborough Bluffs, over one-half the sediment is stratified fine sand, the rest being dense silt and varved clay. Karrow indicates that the genesis of these deposits appears to be lacustrine with stream and deltaic sediments occurring at higher elevations.

The Thorncliffe Formation has been identified by Karrow (1967) in exposures along the West Branch of Duffins Creek. For the present study, these exposures have been correlated with subsurface data available from water-well records (Map 3) on file with the Ministry of the Environment. The linear distribution of permeable materials (sands and gravels) in the subsurface and their relative position to one another, as outlined on Map 5, suggests that a series of encroaching, high-level lakes were initiated after the withdrawal of the Early Wisconsinan ice sheet that deposited the Sunnybrook Till. These high-level proglacial lakes were formed by a readvance of the ice into the Ontario basin, with a probable ice front near the middle of the basin. Three major phases of lake levels, early, intermediate and late, have been identified from the distribution of sediments in the subsurface at elevations of 245 to 301 feet above sea level (asl), 298 to 347 feet asl and 348 to 425 asl, respectively (Maps 6 to 9 inclusive). Associated features such as bars, spits and deltas appear to have existed during the various lake stages. These beach deposits have been interpreted to be part of the Thorncliffe Formation in the study area, although their complex nature is only poorly understood due to the lack of control. Some similar, deltaic-like deposits (the Clarke Deposits) have been identified at an elevation of approximately 320 feet asl in the Lake Ontario bluffs near Bowmanville by Singer (1973). It is suggested that the Clarke Deposits in the Bowmanville area are equivalent to the early lake phase of the Thorncliffe Formation at an elevation of 245 to 301 feet asl in the Duffins Creek area; assuming that the westward decrease in elevation due to differential uplift is approximately 30 feet as indicated by the tilt in the Lake Iroquois shoreline.

Seminary Till ... According to Karrow (1967) the Seminary Till is a silty sand till varying in thickness from nearly zero up to 26 feet and represents a minor advance of no great inland extension in the Scarborough area. Surface exposures of the Seminary Till have not been identified in the study area. Subsurface information suggests that this till is present and appears to represent an ice advance between the early and intermediate lake phases of the Thorncliffe Formation.

The successive shorelines of the intermediate lake phase of the Thorncliffe Formation, as represented by the deposits that overlie the Seminary Till, generally conform to that of the early lake phase but at a higher elevation. This suggests that the ice advance that deposited the Seminary Till did not modify the existing landscape to any great extent and did not retreat to the previous ice-front position. The sandy nature of this till may

be in part attributed to overriding and incorporation of the beach sand from the early lake-phase deposits.

Meadowcliffe Till .... The Meadowcliffe Till has been tentatively identified at the bottom of an abandoned gravel pit near the western limits of the Town of Ajax, east of Duffins Creek. The appearance of this till is similar to that of the Sunnybrook Till although carbonate analyses of the matrix material show differences as illustrated in Table 3 below:

TABLE 3. COMPARISON OF THE MEADOWCLIFFE AND SUNNYBROOK TILLS (Karrow, 1967)

Till	Total Carbonate (%)	Calcite/Dolomite
Sunnybrook Till (22 samples)	12½	0.9
Meadowcliffe Till (9 samples)	30	4.0

Analysis of the till from the gravel pit in the Town of Ajax indicated a total carbonate content of 32.5% and a calcite to dolomite ratio of 4.81.

In the Scarborough Bluffs, the Meadowcliffe Till has a uniform thickness of 35 to 40 feet and reaches up to a thickness of 80 feet inland. Karrow (1967) indicates that this till appears to extend farther to the north than the underlying Seminary Till, but is still of limited, known extent. Singer (1973) has identified the Meadowcliffe Till in the Lake Ontario bluffs in the Bowmanville area. Only a minimum of information is available regarding the Meadowcliffe Till in the study area and data from water-well records suggest that this till likely represents an ice advance between the intermediate and late, lake phases of the Thorncliffe Formation.

Karrow (1967) indicates that the fine texture of the Meadowcliffe Till is a result of the incorporation of fine-grained lake sediments that were deposited in a proglacial lake that was created when the ice sheet that deposited the previous till sheet (Seminary Till) retreated into the Lake Ontario basin. Both the Seminary and Meadowcliffe Tills are considered to represent minor ice advances, indicating a general cooling of the climate just prior to the major Late Wisconsinan ice advance.

Leaside Till ... The Leaside Till represents the last Wisconsinan ice advance in the Toronto-Bowmanville area. Where exposed (Map 4), this till is observed to be a silty sand till with a high stone content. Carbonate analyses of the till matrix in the study area are comparable to those values reported by Karrow (1967) in the Scarborough area and are listed in Table 4.

TABLE 4. CARBONATE ANALYSES OF THE LEASIDE TILL

Area	Total Carbonate (%)	Calcite/Dolomite
Scarborough (Karrow, 1967) (26 samples)	31.0	4.0
Duffins Creek (9 samples)	30.6	5.0

A break in the deposition of the Leaside Till, represented by a thin sand seam or discontinuous beds of sand or sand and gravel up to 18 feet in thickness, has been observed in some sections along the present-day Lake Ontario bluffs and along the valley walls of Duffins Creek. According to Karrow (1967), these two till sheets represent two ice advances separated by a very short time interval and are considered to be part of the Leaside Till. This same feature was observed in the Bowmanville area by Singer (1973).

In some sections along the Lake Ontario bluffs, up to seven feet of the uppermost Leaside Till shows (one-half inch thick) thin pseudo-bedding, grading upward from a silty sand till, through a silty clay till with few stones into beds of varved clay. This feature is probably indicative of the retreat of the ice edge in standing water that was dammed up around the periphery of the ice.

Lake Iroquois Deposits ... Karrow (1967) indicates that high-level lakes were formed during the retreat of the ice front to the eastern end of Lake Ontario. Meltwaters were dammed up between the higher land surface and the ice front that was retreating to the east in the Lake Ontario basin. The levels of these peripheral lakes dropped as lower outlets were uncovered by the retreating ice. Lake Iroquois was formed when an outlet stabilized at Rome, New York, while the ice retreated to the St. Lawrence valley.

Wave action in Lake Iroquois modified the drumlinized till plain that resulted from the ice sheet that had deposited the Leaside Till over the area. A wave-eroded bluff, (Map 4) ranging in height from 20 to 70 feet and trending northeast across the northwest corner of the study area, was cut into the till plain. This prominent feature serves as a physiographic boundary separating the wave-modified till plain or lake plain to the southeast from the irregularly rolling and ice-fluted surface to the northwest. Longshore currents in Lake Iroquois removed the material in the bluffs and exposed older beds where the till cover was thin. The base of the wave-cut bluff is at an elevation of approximately 480 feet asl and is coincident in part with the shorelines from the late lake phase of the Thorncliffe Formation (Map 5) commencing at an elevation of 385 feet above sea level. The writer believes that some of the sediments previously mapped as Lake Iroquois deposits belong to the Thorncliffe Formation and the surface materials may have only been reworked by currents in Lake Iroquois.

Granular deposits of sands or sands and gravels constitute the near-shore facies of Lake Iroquois. A relatively-thin veneer of beach sands is generally found in close proximity to the Iroquois bluff. In some areas, where erosion was dominant, a boulder pavement derived from the winnowing of fines from the coarser material comprising the Leaside Till, marks the high-energy zone of Lake Iroquois. Within the study area, two embayments are present in the Iroquois shoreline across which gravel bars were built. These embayments were low areas between drumlin ridges that were carved by the glacier on the Leaside Till plain. Erosion of the headlands resulted in the development of high cliffs on the ends of the drumlins that projected into Lake Iroquois. The sediment from the cliff erosion was deposited as gravel bars across the bays. The present-day East Branch of Duffins Creek and a tributary to the west of the Creek breach the shoreline at these embayments (Map 4). In contrast, the West Branch of Duffins Creek cuts through a straight stretch of shoreline, in a gorge approximately 150 feet deep, having eroded over 100 feet of shoreline since the disappearance of Lake Iroquois. Much of the granular deposits have been exploited for building materials and only remnants of these deposits are present in the area today.

Deep-water sedimentation partially filled the depressions in the offshore area covered by Lake Iroquois. Fine-grained deposits of varved clay and stratified silt tend to blanket the underlying till plain to the edge of the present-day Lake Ontario shore. Drumlin ridges, trending northwest-southeast in the southern part of the area, rise through the lake plain and do not appear to have been greatly modified by the wave action in Lake Iroquois; whereas some of the higher land to the north appears to have been levelled and smoothed.

When the St. Lawrence valley became free of ice, the waters of Lake Iroquois were drained. Remnants of shorelines at 350 and 300 feet asl (Map 4) suggest that the lake level dropped in stages as the ice front retreated and lower outlets to the sea were uncovered. None of the shorelines are well-developed, suggesting that the time interval between the stages was of short duration. Karrow (1967) indicates that Lake Iroquois drained to more than 200 feet below the present level of Lake Ontario approximately 10,000 years ago. Differential uplift of the land surface has gradually raised the water in the Ontario basin to its present level at approximately 245 feet asl and the formerly horizontal shoreline of Lake Iroquois has been tilted up to the northeast Coleman (1937) reported that the shoreline was at an elevation of 362 feet asl in the City of Hamilton at the west end of Lake Ontario and 730 feet asl towards the eastern end of the Lake, at Pancake Hill north of the City of Belleville. The differential rise in the shoreline increases to the northeast along the direction of maximum tilt at N 20° E (Coleman 1937). Karrow (1967) indicates that the average rise of the shoreline in the Scarborough area, adjoining the study area on the west, is approximately 2.5 feet per mile.

Recent Deposits ... Alluvial deposits are found along most of the stream courses in the study area. The material forming the banks and underlying the streams is subjected to erosion whereby the finer material is carried downstream and deposited along the flood plain and streambed. The coarser material, such as boulders in the till, is left behind to form a lag deposit in the streambed

The lower reaches of the streams flowing into the lake are presently being submerged by the rising water level in Lake Ontario and marshes have developed near their mouths. Notable examples in the study area are the marshes around Frenchman's Bay and the mouth of Duffins Creek (Map 4).

The sediments along the Lake Ontario beach are the result of the erosion of the materials in the present-day bluffs and consist mainly of sand and some gravel blanketing older deposits. Large boulders, eroded out of the till, litter the beach in some areas and help to protect the base of the bluffs from erosion.

HYDROGEOLOGY

GROUND-WATER OCCURRENCE

Ground water is an aspect of the hydrologic cycle which has resulted from the infiltration of moisture at the earth's surface, moving through the "unsaturated zone" into the "saturated zone". The water stored in the saturated zone is called ground water. Under the influence of gravity, ground water moves to a point of natural or artificial discharge in a stream, lake or well. Natural recharge to this system occurs either directly from precipitation infiltrating into the ground or indirectly from snowmelt, standing bodies of water and surface streams.

An aquifer is defined as a water-bearing horizon that will transmit significant amounts of water into a well. In the exploration for ground-water resources, the connotation of the wording "significant amounts" further defines the term aquifer with respect to the usage of water for domestic, industrial or municipal supplies. An aquifer in the context of this report is one that will supply water for at least domestic use. In the study area, aquifers are found both within the overburden and in the bedrock.

Ground water is stored in the interstices or openings and pore spaces between the grains comprising the material through which the ground water moves. The capacity of any material to absorb, yield or hold water is dependant on the porosity and permeability of the material (i.e. the total number of interstices or voids and the interconnection of these interstices, respectively). Thus, a high porosity material such as shale or clay will not yield large quantities of water due to absorption phenomena resulting from the molecular size and poor interconnection of the pore spaces.

Within the overburden, the most productive materials are the granular deposits of sand and gravel. The extent of these granular deposits has been delineated in Maps 6 to 9 inclusive, for the study area, as indicated from data in water-well records on file with the Ministry of the Environment. In a previous section of this report, it was suggested that these granular materials represent ancient beach deposits that were overridden by the latest Wisconsinan glaciation. These deposits are presently being utilized as the primary source of ground water in the study area.

Numerous bored and dug wells penetrating low water-yielding materials such as glacial deposits of till or glaciolacustrine clays and silts are also being used as a source of ground water. The yield from the wells completed in these materials is essentially controlled by the storage capacity of the large-diameter wells. Recent studies in the prairies (Meyboom et al, 1966) suggest that the movement and storage

of ground water in glacial tills is within joints developed in the till.

The shale bedrock in the study area is generally a poor aquifer. Microscopic examination indicates that its porosity is low resulting from the consolidation and compaction of the shale since its deposition. Joints, fractures, cleavage planes and faults were subsequently developed in the bedrock, probably as a result of tectonic processes. Other processes, such as those associated with weathering, have enlarged these planes (including the original bedding planes) creating secondary porosities through which the ground water presently flows. These secondary openings tend to become tighter and fewer in number with increasing depth.

GROUND-WATER LEVELS

The change in storage of the ground-water reservoir can be identified by the measurement of rising and declining water levels in water wells or boreholes. During periods of high precipitation, storage in the ground-water reservoir is increased, after the soil moisture deficiency (SMD) in the unsaturated zone is replenished. When the SMD is satisfied, the infiltrating water will percolate downwards into the saturated zone under the influence of gravity. Conversely, storage is decreased under conditions where the infiltrating water is intercepted before reaching the saturated zone, while discharge from that zone continues. These conditions occur during periods of low precipitation and/or excessive use of ground water by man or vegetation.

An established, observation-well network of private and abandoned water wells (Sibul et al, 1977) was supplemented with three observation-well installations constructed by the Ministry of the Environment for the IFYGL program (Map 1a). The change in water levels was computed for the wells in this network over the Field Year period from April 1st, 1972 to March 31st, 1973 and the results are presented in Table 5. The data in Table 5 suggest than an overall increase in the storage of the ground-water reservoir occurred during the Field Year. This is indicated by the average rise of 0.85 feet in the water levels of the observation-well network from April 1, 1972 to March 31, 1973.

TABLE 5. STATIC LEVELS AND CHANGE IN WATER LEVELS (s) OF THE OBSERVATION-WELL NETWORK IN THE IFYGL DUFFINS CREEK STUDY AREA

Well	Diameter	Depth	Static Level Apr. 1/72	Static Level Mar.31/73	s	Average s
329	6"	12'	7.80'	8.60'	-0.80'	
308	6	14'	3.34'	3.35'	-0.01'	
P-2	2"	16'	6.19'	5.85'	+0.34'	
P-1A	2"	17'	4.88'	2.75'	+2.13'	
P-1B	2"	17'	5.23'	2.87'	+2.36'	
302	48"	20'	2.90'	0.60'	+2.30'	
301	48"	23'	17.50'	15.45'E	+2.15'	
						+1.21
P-1A	½"	30'	4.64'	2.84'	+1.80'	
P-2	½"	36'	7.80'	5.98'	+1.82'	
330	2"	40'	25.00'E	25.09'	-0.09'	
303	48"	44'	5.04'	4.58'	+0.46'	
P-1A	½"	45'	4.66'	3.17'	+1.49'	
336	2"	47'	40.80'E	40.17'	+0.63'	
P-2	½"	49'	6.53'	7.27'	-0.74	
						+0.62
331	2"	73'	28.70'E	28.53'	+0.17'	
337	2"	92'	39.92'E	38.26'	+1.65'	
332	2"	157'	13.80'E	13.62'	+0.18'	
333	2"	238'	12.95'E	12.65'	+0.30'	
304	6"	424'	189.43'	189.38'	+0.05'	
						+0.47
						+0.85

E = estimated from observation-well hydrograph

Climatological data, presented in Table 6 below, indicate that excess precipitation over the long-term annual average contributed to the rise of ground-water levels that occurred in the study area during the Field Year. It is assumed that the excess of 4.29 inches over the long-term annual average of 31.91 inches recorded at the Pickering-Audley station, occurred over all of the study area. This excess

precipitation is reflected by the overall rise of 0.85 feet in the ground-water levels of the observation-well network.

TABLE 6. AVERAGE ANNUAL PRECIPITATION IN THE IFYGL DUFFINS CREEK STUDY AREA

Station	Annual Precip. (1/4/72-31/3/73)	Average Long-Term (12 yrs) Ann.Precip.	Deviation from Long Term
Frenchman's Bay	36.77"	-	-
Pickering	35.82"	-	-
Greenwood MTRC	35.58"	-	-
Pickering-Audley	36.20"	31.91"	+4.29"
Station Average	36.09"		

The water-level data (Table 5) suggest that the magnitude of the overall rise in water levels for the Field Year period decreases with increasing depth of the well. Wells under 30 feet in depth show an average increase in water level of 1.21 feet, whereas wells between depths of 30 to 50 feet show a smaller increase of 0.62 feet. This feature is also illustrated in site P1-A near the shore of Lake Ontario, where observation-well installations at depths of 17, 30 and 45 feet showed a progressive decrease in the net water-level change of +2.13, +1.80 and +1.49 feet, respectively, over the same time period.

In addition, it appears that water levels at site P1-A are influenced by changes in the level of the Lake as indicated by the similarity of the lake and well hydrographs for the Field Year period (Figure 2). The high and low-water stages for both Lake Ontario and the observation wells at site P1-A occurred during the months of June and November, respectively (Figure 2), whereas the high and low-water stages of the other observation wells (inland from Lake Ontario) occurred during the months of April and September, respectively (Figure 3).

GROUND-WATER MOVEMENT

Ground-Water Flow Field

The ground-water flow field is a three-dimensional field that occurs from the top of the saturated zone down to a depth where ground-water flow becomes impossible (i.e. where

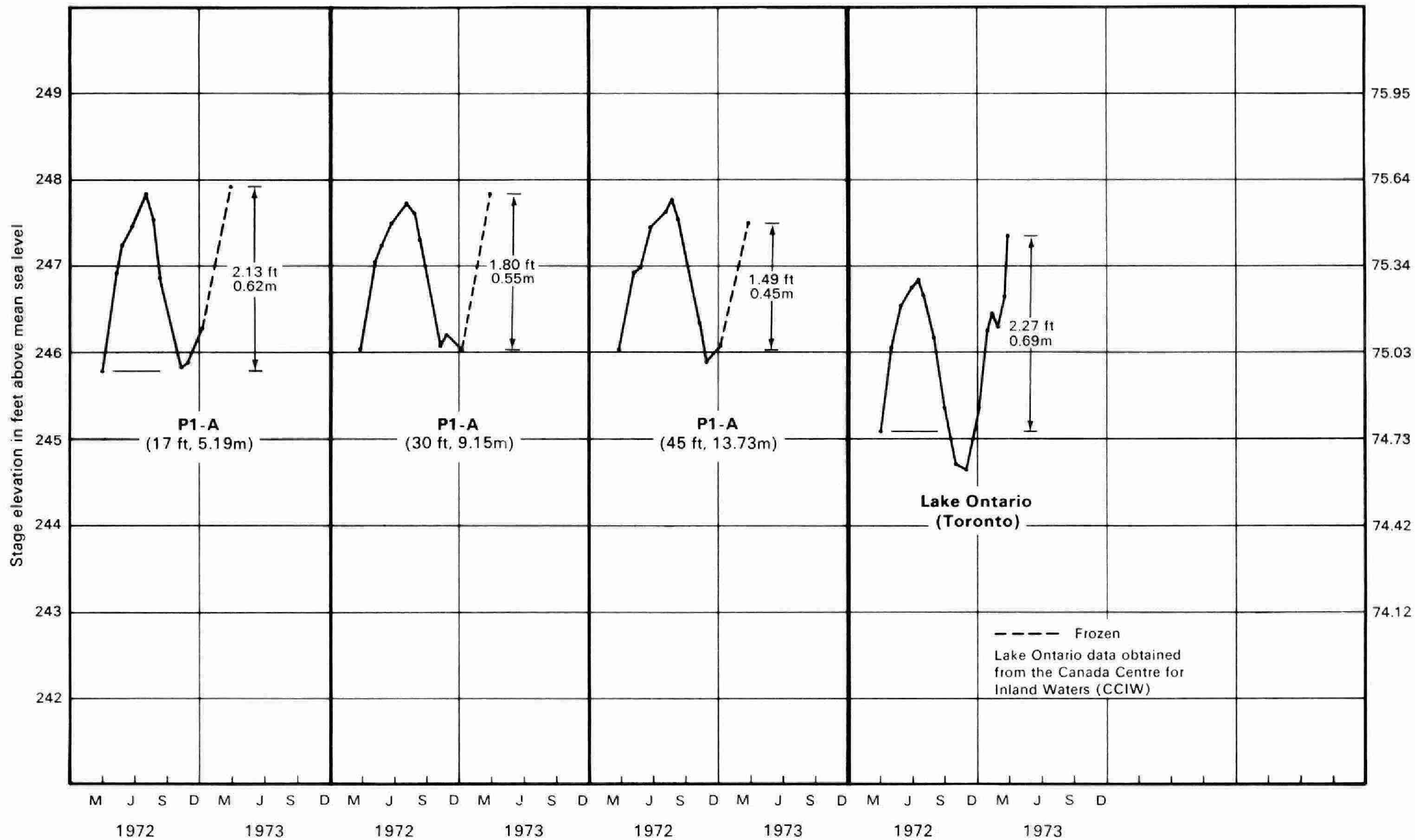

Figure 2. Hydrograph comparison of Lake Ontario and observation wells at site P1-A in the IFYGL Duffins Creek study area.

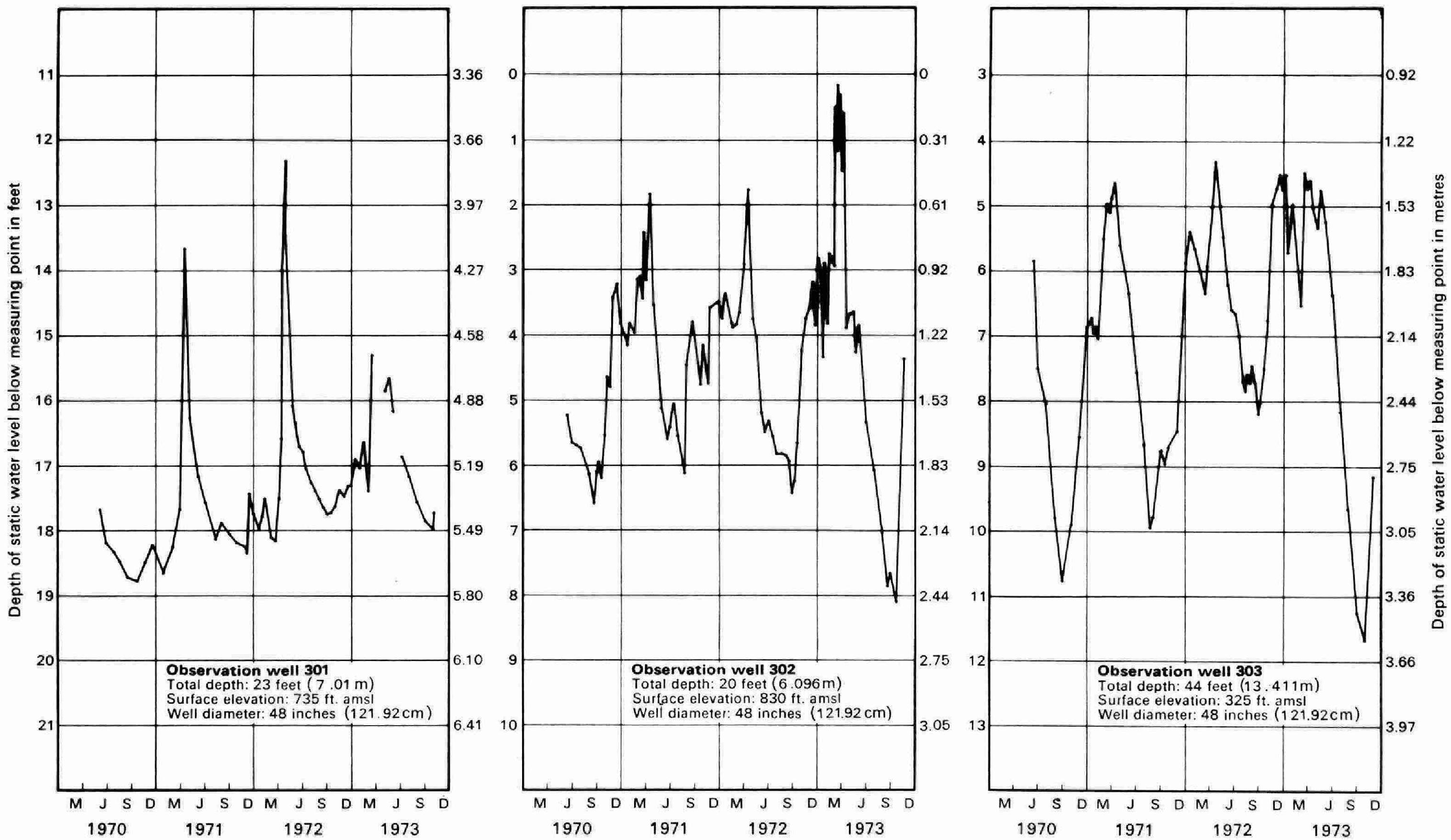

Figure 3. Observation-well hydrographs for wells 301, 302 and 303 in the vicinity of the IFYGL Duffins Creek study area.

the material in the saturated zone becomes completely impermeable). The ground-water head at any point in this field can be expressed in terms of total head defined by Hubbert (1953) as the sum of pressure head, elevation head and velocity head at that point; however, as the velocity head is so small for ground-water considerations it can be neglected. The static water level (the level to which water rises) in a non-pumping well is a measure of the ground-water head at the point where the water was found.

The total-flow vector (Meyboom et al, 1966) of the three-dimensional ground-water field can be resolved into two, two-dimensional horizontal and vertical vectors. From these, the "flow resultant" is the flow component in the vertical plane and the "horizontal component" is the flow component in the horizontal plane (Meyboom et al, 1966). In either case, the component of flow that is depicted ("flow resultant" or horizontal component") is assumed to essentially represent the total-flow vector of the ground-water flow field.

Water-Level Data

As indicated above, the static water levels in wells are a measure of the potential causing ground-water flow. Water-level data from water-well records on file with the Ministry of the Environment indicate that the average static water level for 342 overburden wells in the study area is 15.5 feet below the ground surface with a standard deviation of 12.6 feet. These data suggest that the static water levels of wells completed in different water-bearing horizons within the overburden are usually found within a few feet of the land surface, regardless of the season or year in which the wells were drilled. Additional information from the observation-well network (Sibul et al, 1977) indicates that the maximum fluctuation of ground-water levels has been less than 10 feet over the past three years of record (Figure 3), or less than one standard deviation from the mean, static water level indicated from the water-well records on file with the Ministry of the Environment. The similarity in the data suggest that the general direction of ground-water flow can be determined from these water-level data. Anomalously deep water levels can usually be traced to excessive withdrawals or consumption of ground water or to deep wells completed in the less active or stagnant part of the ground-water reservoir.

Potentiometric Surface

The water-level data from water-well records in the study area were used to compile a potentiometric-surface map for the ground water in the overburden (Map 10). A potentiometric map was not prepared for wells completed in the bedrock due to the paucity of wells penetrating the bedrock in the

study area. The hydraulic-head values (i.e. water-level elevations) for these wells are shown separately on the map prepared for the overburden (Map 10). The similarity in head values for the two sets of data, overburden and bedrock, suggests that they are hydraulically connected. For the purposes of this report, the overburden and uppermost part of the bedrock are considered to constitute the active part of the ground-water reservoir.

With respect to the potentiometric-surface map (Map 10), lines of equal potential were interpolated between values of hydraulic head obtained from the water-well records on file with the Ministry of the Environment. By definition, ground-water flow is at a direction normal to the lines of equal potential. Examination of Map 10 indicates that the potentiometric surface conforms to the topographic expression of the ground surface and may be considered as a subdued replica of the physiography in the study area. The ground-water divides appear to be generally coincident with the surface-water divides and by analogy, areas of recharge and discharge are topographic highs and low, respectively. Thus ground-water flow, in a lateral direction, is controlled by the topography; movement being from topographically high to topographically low areas.

Hydraulic Gradient

Assuming that the "horizontal component" of flow (as illustrated in Map 10) represents the total-flow vector of the ground-water flow field, the slope of the potentiometric surface is the hydraulic gradient under which ground-water movement occurs. Ground-water movement is dependant on the hydraulic gradient according to Darcy's Law, $Q = KIA$, where:

Q = quantity of flow
K = coefficient of permeability of the porous material
I = hydraulic gradient
A = cross-sectional area through which movement takes place.

The hydraulic gradient (I) is the head loss (in feet of water) per unit distance (foot) of flow path, resulting from the frictional resistance to flow within the voids of the material through which the ground water moves. As indicated earlier, the potentiometric surface (Map 10) is similar to the land surface and ground-water flow is from high to low potential in a direction normal to the lines of equal potential. The hydraulic gradient (I) is in the order of 0.005 (feet per foot) for the bulk of the study area to 0.014 (feet per foot) in the vicinity of Frenchman's Bay, near the western part of the study area.

If the "horizontal component" of ground-water flow does not represent the total-flow vector of the ground-water flow field, then the slope of the potentiometric surface is only a component of the true hydraulic gradient. It would then be assumed that the "flow resultant" (in the vertical plane) represents the total-flow vector of the ground-water flow field. In areas where there is a strong downward or upward component of flow, the vertical gradient determined from observation wells or piezometers, can approximately represent the hydraulic gradient. The vertical gradient is the head loss (in feet of water) per unit distance (foot) of depth.

For the Field Year program, piezometer nests were installed at several sites (Map 1a) in order to determine the potential distribution of the ground water in the subsurface. Head measurements (static water levels), obtained from these piezometer installations at depth, were used to compute the vertical gradients at the sites and the results are presented in Table 7 below:

TABLE 7. COMPUTED, VERTICAL HEAD GRADIENTS IN PIEZOMETER NETS P1-A, P1-B and P2 ON MAY 2, 1972, NOVEMBER 6, 1972 and MARCH 29, 1973.

Nest	Material	Depth	Vertical Gradient			
			2/5/72	6/11/72	29/3/73	Average
P1-A	overburden	17'				
			+0.007	+0.020	-0.007	+0.007
	overburden	30'				
			-0.007	+0.016	-0.022	-0.004
	overburden	45'				
P1-B	overburden	17'				
			-0.020	NA*	NA*	-0.02
	overburden	31'				
P2	overburden	16'				
			-0.011	-0.021	-0.007	-0.013
	overburden	36'				
			-0.101	-0.167	-0.100	-0.123
	bedrock	49'				

*NA = data not available.

The vertical gradient ranges from -0.167 to +0.020 (feet per foot of depth) in the study area, as illustrated in Table 7 above. Intermittent upward movement is indicated at site P1-A, near Lake Ontario, at various times of the year, suggesting that this is an area of ground-water discharge. The negative vertical gradients measured at other times of the year may be local effects due to fluctuating water levels in Lake Ontario. Average vertical gradients at site P1-A have the same order of magnitude as the estimated hydraulic gradient for the "horizontal component" of ground-water flow in Map 10. This suggests that the total flow-vector of the ground-water flow field can be approximated by either the vertical or the horizontal vector of flow at site P1-A (ie "flow resultant" or "horizontal component").

The negative vertical gradients computed for site P2 (Table 7) suggest that downward movement of ground water occurred at this site throughout the period of investigation. Within the overburden at this site, the vertical gradient is similar to the estimated hydraulic gradient for the horizontal component of ground-water flow (Map 10). This suggests again, that either the "horizontal component" or the "flow resultant" approximates the total-flow vector of the ground-water flow field. Strong downward movement of ground water is indicated by the average vertical gradient of -0.123 between the overburden and bedrock at this site. If natural ground-water flow is wholly in the vertical direction at this site, the observed vertical gradient, between the overburden and the bedrock, must reflect a decrease in permeability of the bedrock (i.e. under these conditions the product of gradient and permeability must remain constant from Darcy's Law, $Q = KIA$, indicating that the permeability of the bedrock is less than that of the overburden).

In summary, the hydraulic gradient under which ground-water movement occurs is similar to the regional topographic gradient which ranges from 0.005 to 0.014 feet per foot. The area near the Lake Ontario shore appears to be in a zone of general ground-water discharge. The area inland from the Lake Ontario shore appears to be in a general area of recharge, including those areas close to creek valleys (e.g. site P2).

AQUIFER CHARACTERISTICS

Introduction

The water-yielding properties of an aquifer are a function of pore size and their interconnection. For quantitative ground-water studies, the most common method for determining aquifer characteristics is by means of a pumping test. The yield of a well, as determined from a pumping test, may be used to provide information on the water-yielding properties of the various aquifers encountered. In addition, pumping-test data may

be used to provide some estimate of the coefficients of transmissibility and permeability (commonly referred to as transmissibility and permeability, respectively) of the materials through which the ground water is flowing. The coefficient of transmissibility (T) is defined as the rate of flow of water in Imperial gallons per day (Igpd) through a vertical strip of the aquifer one foot in width and extending the full saturated thickness of the aquifer under a hydraulic gradient of one foot per foot at the prevailing temperature of water. The coefficient of permeability (K) may be determined using the relation

$K = \frac{T}{m}$, where:

K = hydraulic conductivity (coefficient of permeability, Igpd/ft^2).

T = coefficient of transmissibility (Igpd/ft).

m = contributing thickness of the aquifer (feet).

In order to evaluate the quantity of ground water discharging to Lake Ontario, an estimate of the permeability or transmissibility of the materials through which the ground water flows was made using well-yield data.

Well Yields

Statistical analyses of specific-capacity data (derived from pumping tests) by means of specific-capacity frequency graphs (Figure 4) provide a convenient method of comparing the water-yielding properties of the different aquifers in the study area. The specific capacity of a well is its yield, in Imperial gallons per minute per foot of drawdown (Igpm/ft), for a stated pumping period and rate, and is numerically expressed as Q/s, where:

Q = pumping rate in Imperial gallons per minute (Igpm)

s = drawdown (loss of head) in feet.

The specific-capacity data for wells completed in the overburden and bedrock were tabulated in order of magnitude and the frequencies were computed by the Kimball (1946) method. Values of specific capacity were plotted against percent of wells on logarithmic-probability paper. The slope of the line indicates the variability of the water-yielding properties of the material; steeper slopes signify greater variability than flatter slopes. Comparison of the frequency curves for the overburden and the bedrock (Figure 4) indicate a similarity in slope (i.e. variability), with overburden wells being more productive than wells completed in the bedrock. For example, 50 percent of the wells completed in the overburden have a specific capacity of 0.5 Igpm per foot or more, whereas 50 percent of the wells completed in the bedrock have a specific

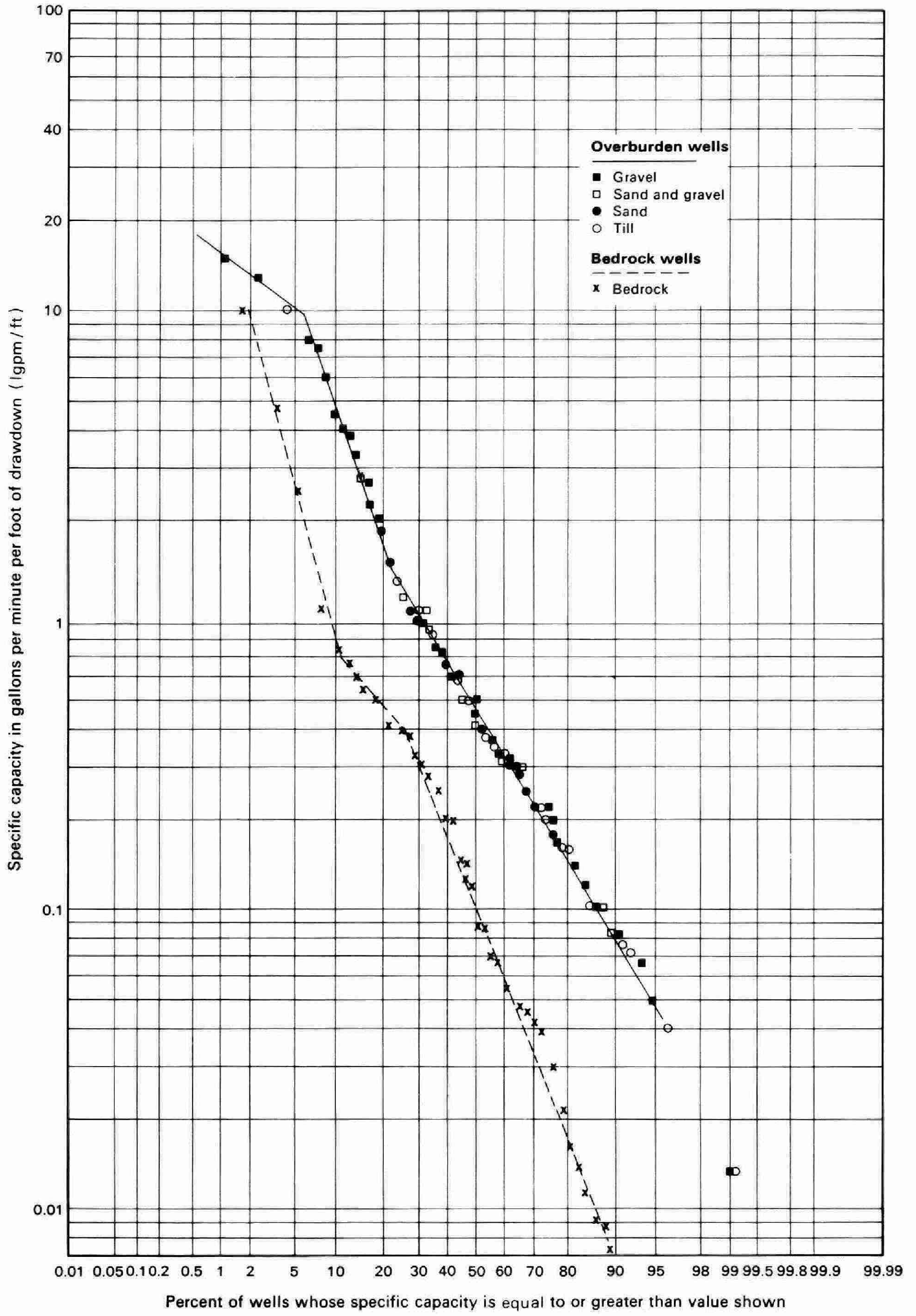

Figure 4. Specific-capacity frequency graphs for bedrock and overburden wells in the IFYGL Duffins Creek study area.

capacity of 0.1 Igpm per foot or more. The specific capacities of overburden wells generally range from 0.08 to 5.0 Igpm per foot of drawdown and the specific capacities of bedrock wells range from 0.07 to 0.7 Igpm per foot of drawdown.

The overburden frequency curve consists of three distintive segments of different slopes. Two of these changes in slope appear to be restricted to the higher-yield gravel wells, suggesting that gravel wells with a specific capacity of 1 to 10 are more variable than those wells above or below that range. A change in slope also occurs in the range of 0.4 to 0.7 Igpm per foot of drawdown for the bedrock frequency curve with slopes on either side of this range being the same. The reason for this slope variability has not been determined to date; however, it may be a result of increased contribution from the overburden to the well through faulty well construction or artificial fracturing of the bedrock surface during drilling, permitting some leakage of the water from the overburden into the uncased portion of the well in bedrock.

Transmissibility (modified non-equilibrium well formula)

Information from water-well records on file with the Ministry of the Environment were utilized to estimate the transmissibility (and by analogy the permeability) of the different materials from short-term pumping tests of wells in the study area. Transmissibilities were obtained using the modified non-equilibrium well formula (Cooper and Jacob, 1964),

$T = \frac{264\ Q}{s}$, where:

T = coefficient of transmissibility (Igpd/ft.)

Q = pumping rate in Imperial gallons per minute (Igpm)

s = change in drawdown per $\log_{10}$ cycle (feet)

The derivation of the formula is based on the following assumptions (Johnson, 1966):

1) The water-bearing formation is uniform in character and permeability in both horizontal and vertical directions.
2) The formation has uniform thickness.
3) The formation has infinite areal extent.
4) The formation receives no recharge from any source.
5) The pumped well penetrates and receives water from the full thickness of the water-bearing formation.
6) The water removed from storage is discharged instantaneously with lowering of the head.

Unfortunately, due to the nature of the data, (lack of observation wells, partial penetration of the aquifer by wells and non-uniformity of the aquifer, etc.), the above assumptions are not met in totality. It is assumed that the transmissibility values obtained from the well-record data are within an order of magnitude of the absolute values.

The results of the computations of permeabilities for the various material in the study area are presented below (Table 8). Permeabilities were computed from transmissibility divided by contributing aquifer thickness (T/m).

TABLE 8. PERMEABILITIES (k) OF THE MATERIALS IN THE IFYGL DUFFINS CREEK STUDY AREA

Material	Number of Wells	Mean K (gpd/ft^2)	Std. Dev. (gpd/ft^2)	Range of K (gpd/ft^2)
Gravel	33	468	822	7 - 3950
Sand & gravel	11	366	455	3 - 1480
Sand	14	77	75	2 - 250
Till, clay, silt	35	15	14	1 - 59
Bedrock	42	6	9	0.1 - 35

Transmissibility (specific capacity)

The coefficient of transmissibility of an aquifer can be estimated from the specific capacity of production wells. The theoretical specific capacity of a well may be written as,

$$Q/s = \frac{T}{114.6\, W_{(u, rw/B)}} \text{, where:}$$

$$u = \frac{2242\, rw^2 S}{Tt}$$

$$\frac{rw}{B} = \frac{rw}{T/P'm'}$$

$W_{(u, rw/B)}$ = well function for leaky artesian aquifers (Hantush 1956)

Q = discharge of pumped well (Igpm)

s = drawdown (feet)

rw = nominal radius of well (feet)

T = coefficient of transmissibility (Igpd/ft.)

S = coefficient of storage

t = pumping period (minutes)

P' = coefficient of vertical permeability of confining bed (Igpd/ft^2)

m' = saturated thickness of confining bed (feet)

Reliable data are not available on the coefficient of storage (S) in the study area. The magnitude of S depends on the elasticity of the aquifer material and the fluid. In confined aquifers, S does not show large variations and ranges from 10^{-6} to 10^{-4} (Kruseman et al 1970). Almost all the wells in the study area on file with the Ministry of the Environment indicate confined conditions, having a static water level above that where the water was found. According to Meyer (Bentall, 1963) any changes in the coefficient of storage (S) correspond to only small changes in the transmissibility (T) and specific capacity (Q/s); therefore, inaccuracy in estimating S generally is not a serious limiting factor.

With regard to the vertical permeability of the confining bed (P'), data have not been compiled on this parameter in the study area to date.

In addition to being dependant on the hydraulic properties of the aquifer and confining beds, the specific capacity of a well will vary as a result of the following factors:

1) rw, the nominal radius of the well (Q/s increases with increasing rw, i.e. directly proportional to log rw^2)

2) t, the pumping period (Q/s decreases with increasing time, i.e. inversely proportional to log t)

3) sw, the well loss (Q/s decreases with an increase in pumping rate in wells with a high sw).

The relationship between the theoretical specific capacity and the coefficient of transmissibility of an artesian aquifer is shown in Figure 5 (after Csallany et al, 1963). It is assumed that the conditions depicted in Figure 5 are applicable in the study area. Permeabilities were computed from specific-capacity data, using Figure 5, for artesian wells in the study area and the results are presented in Table 9 below. According to Walton (1962) and Walton et al (1962), the coefficient of transmissibility, computed from specific-capacity data, does not vary significantly between a pumping period of one

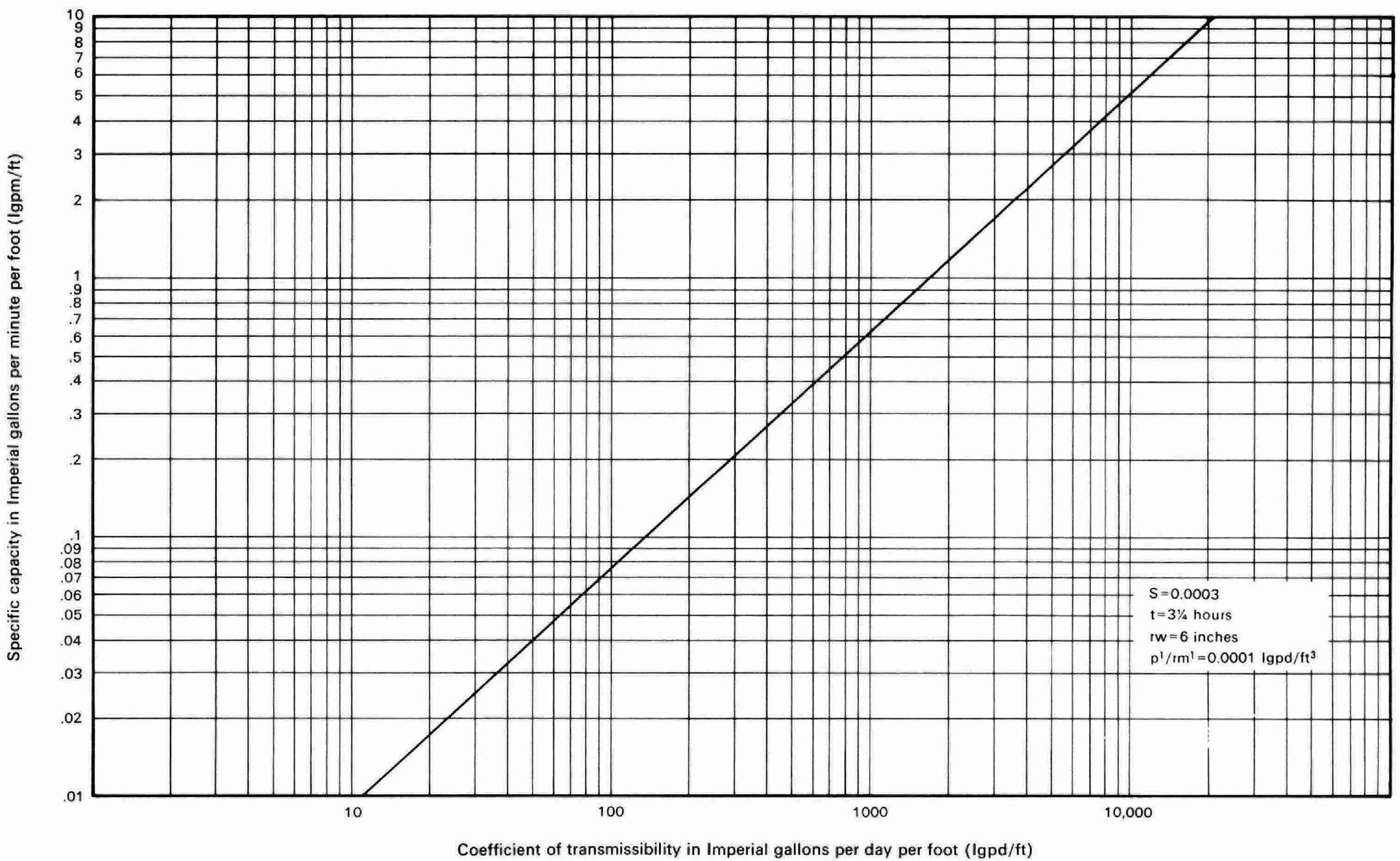

Figure 5. Theoretical relationship between specific capacity and the coefficient of transmissibility (after Csallany and Walton, 1963).

TABLE 9. COMPARISON OF PERMEABILITIES ("K") DERIVED FROM SPECIFIC-CAPACITY AND PUMPING-TEST DATA OF THE SAME WELLS IN THE IFYGL DUFFINS CREEK STUDY AREA

Material	No. of wells	Mean diameter (inches)	Mean pumping period (hours)	Mean "K" from specific capacity data ($Igpd/ft^2$)	Mean "K" from the modified non-equilibrium well formula ($Igpd/ft^2$)
gravel	31	5.81 (1.18)	4.06 (2.34)	1357 (2118)	438 (772)
sand & gravel	10	5.65 (0.82)	3.50 (1.58)	842 (920)	304 (443)
sand	8	5.21 (0.68)	3.12 (1.55)	244 (210)	73 (68)
till, clay, silt	4	5.87 (0.59)	2.81 (1.47)	240 (108)	25 (29)
bedrock	42	5.82 (1.04)	3.23 (2.04)	28 (39)	7 (9)

(1.18) standard deviation

to 8 hours and a limited range of the nominal radius (rw) of the well. In order to minimize these errors, only wells in the study area with a pumping period ranging from 1 to 10 hours and with a well diameter of 4 to 8 inches were used in the computations of permeability presented in Table 9.

The data in Table 9 indicate that the permeabilities derived from the specific-capacity data are larger by approximately a factor of three than those permeabilities derived from the modified non-equilibrium well formula (Table 8). Sufficient data on well losses (sw) and hydraulic properties of the confining beds are not available to delineate the permeability from the specific-capacity data to any greater degree of accuracy.

GROUND-WATER CONTRIBUTION TO LAKE ONTARIO

Introduction

The Darcy formula, Q = T I L, was used to compute the amount of direct ground-water inflow to Lake Ontario, where:

Q = quantity of water in Imperial gallons per day (IGPD)
T = coefficient of transmissibility (I gpd/ft)
I = hydraulic gradient (feet per foot)
L = width of flow cross section (feet).

In order to evaluate the values to be used for the parameters listed above, several assumptions on the ground-water flow field were required. The assumptions used in the determination of ground-water inflow to Lake Ontario are listed below with respect to contributing area, depth of active flow, saturated thickness, transmissibility and hydraulic gradient.

Contributing Area

As indicated in an earlier section, the area near the Lake Ontario shore is considered to be in a zone of general ground-water discharge. In order to facilitate the computation of ground-water inflow to the Lake, it was assumed that the area within a distance of one mile from the shore was representative of the conditions in the zone of ground-water discharge.

Depth of Active Flow

The mean value of bedrock penetration for 112 wells completed in the bedrock within the study area was found to be 30 feet. Wells completed within the assumed zone of ground-water discharge (contributing area) indicate a mean value of 10 feet for bedrock

penetration. From these data it was assumed that the mean value would reflect the practical limit of ground-water exploration for domestic supplies and therefore, significant ground-water flow in the bedrock would not extend below 50 feet of bedrock penetration. This arbitrary value of 50 feet of bedrock penetration is considered to be the boundary between the active and stagnant parts of the ground-water reservoir.

Saturated Thickness

The static water level reported in the water-well records was used to determine the saturated thicknesses of materials in wells within one mile distance of the Lake Ontario shore (Table 10). In some wells, a relatively low, static water level in conjunction with a thin overburden thickness indicated that the contribution of ground water from the overburden was negligible.

Transmissibility

Permeability values, derived from short-term pumping tests (Table 8) using the modified non-equilibrium well formula (Cooper & Jacob, 1964), were used to compute transmissibilities in the zone of ground-water discharge. The various materials reported in the logs of wells within a distance of one mile from the shore were assigned a permeability which was then multiplied by the saturated thickness to determine the transmissibility. The total transmissibilities for each well were summed and an average transmissibility of 930 Igpd/ft. (Table 10) was determined for the materials within the zone of ground-water discharge.

Hydraulic Gradient

The average hydraulic gradient, I, was assumed to be 0.010 (Map 10) for the study area as indicated in an earlier section on ground-water movement.

Computation of Ground-Water Inflow

The values for T and I, as derived above, were substituted in the Darcy formula to obtain a value of ground-water contribution per mile length of shore line as follows:

$$
\begin{aligned}
Q &= TIL \\
&= 933 \times 0.010 \times 5280 \\
&= 49{,}262 \text{ Igpd per mile length} \\
&= 0.092 \text{ cubic feet per second (cfs) per mile length.}
\end{aligned}
$$

It is assumed that this value of ground-water discharge for the study area is representative of 35 miles of Lake Ontario shoreline from the mouth of the Humber River, near the western limits of the City of Toronto, to the City of Oshawa, giving a grand total of 3.2 cfs for direct ground-water discharge to Lake Ontario. This value is similar to the values of 2.61 and 3.29 cfs for roughly the same area as computed by Haefeli (1972).

TABLE 10. MEAN VALUES OF TRANSMISSIBILITY (T), STATIC WATER-LEVEL DEPTH, OVERBURDEN THICKNESS AND BEDROCK PENETRATION FOR WELLS COMPLETED WITHIN ONE MILE OF THE LAKE ONTARIO SHORE IN THE IFYGL DUFFINS CREEK STUDY AREA.

	No. of Wells	Mean T (gpd/ft.)	Mean Over-burden thickness (ft.)	Mean Bed-rock Pen-etration (ft.)	Mean Static Level (ft.)
wells completed in the overburden	56	1036(810)	33(14)	-	15(11)
wells completed in the bedrock	18	610(219)	45(22)	10*(14)	27*(21)
all wells	74	933(735)	36(17)		18*(15)

(219) standard deviation
* anomalous well with 193 feet of bedrock penetration and static water-level of 234 feet was not considered.

Additional Ground-Water Inflow

Relatively high bluffs occur along the Lake Ontario shore, west of the study area, in the Borough of Scarborough. The height of these bluffs averages approximately 410 feet asl or 160 feet above lake level, along a nine-mile stretch of shoreline. Assuming that the discharge of ground-water may be occurring in the lower one-third (Meyboom et al, 1966) of these bluffs (53 feet) the value of 3.2 cfs would then be minimal for the ground-water discharge to Lake Ontario from this hydro-geological region.

A calculation of the additional discharge from this stretch of the Scarborough Bluffs was made using values of transmissibility derived from the Duffins Creek study. The average permeability per foot of saturated overburden thickness is 57.5 gpd/ft. (Table 10, "wells completed in the overburden" column: $1036 \div (33-15) = 57.5$). The mean saturated thickness of the overburden in the study area is 18 feet (Table 10, "all wells" column: $36-18 = 18$). The additional saturated overburden thickness in the Scarborough Bluffs section would then be 35 feet (subtracting the mean saturated thickness of the study area from the estimated value of 53 feet of saturated thickness in the Scarborough Bluffs). Substituting these values in the formula:

$$Q = TIL = KmIL = (57.5) \times 35 \times (0.010) \times (5280 \times 9)$$

$$= 954{,}700 \text{ IGPD} = 1.77 \text{ cfs.}$$

Therefore, an additional 1.8 cfs of ground water may be discharging directly to Lake Ontario from the highest part of the Scarborough Bluffs giving a grand total of 5.0 cfs of ground-water discharge to Lake Ontario.

SUMMARY AND CONCLUSIONS

A hydrogeological evaluation of the lower part of the Duffins Creek drainage basin was made for the IFYGL program, in order to estimate the amount of ground-water inflow to Lake Ontario, in the hydrogeologic region along the north shore of Lake Ontario from the Humber River near the western limits of the City of Toronto to the City of Oshawa (Figure 1). The hydrogeology of the study area was assessed utilizing field investigations of the geology, test drilling to provide information on aquifer characteristics, subsurface geology and ground-water levels and information from water-well records on file with the Ministry of the Environment.

The study area lies in parts of the physiographic regions of the Iroquois Plain and South Slope (Map 1). The Iroquois Plain is the lowland which borders Lake Ontario, that was inundated and smoothed by wave action of glacial Lake Iroquois. The South Slope region borders the study area to the northwest and consists of drumlinized till plain. Regional topographic gradients range from 25 feet per mile in the Iroquois Plain to 150 feet per mile in the South Slope region.

The climate of the study area is influenced by the presence of Lake Ontario to the south. A long-term annual precipitation and temperature of approximately 32 inches and 44°F, respectively, is considered to be representative over the study area.

The bedrock of the area is comprised of Upper Ordovician shales of the Whitby Formation which are overlain by Wisconsinan drift of the Pleistocene Epoch. Two major bedrock valleys were delineated in the study area and they are roughly coincident with present-day drainage. Subsurface information from water-well records on file with the Ministry of the Environment indicates that the area was inundated by high-level glacial lakes during Wisconsinan time. The permeable materials (sand and gravel sediments) of the Thorncliffe Formation that were deposited in these lakes are presently being utilized as a source of water for domestic and agricultural uses. Correlation of the unconsolidated materials in the study area with materials to the east (Bowmanville area) and to the west (Scarborough area) is given in Table 2.

An excess of 4.29 inches of precipitation over the long-term annual average during the IFYGL period (April 1, 1972 to March 31, 1973) resulted in a rise of the static level of 0.85 feet in the ground-water reservoir of the study area (Table 6).

Water-level data from water wells drilled in the study area suggest that a hydraulic connection exists between the overburden materials and the upper part of the bedrock. The mean static water-level for overburden wells in the study area is 15.5 feet below the ground surface, and it is suggested

that the potentiometric surface conforms to the topographic expression of the land surface (Map 10). Ground-water divides are generally coincident with surface-water divides indicating that ground-water movement is from topographically high to topographically low areas. Piezometric data indicate that the area near the Lake Ontario shore appears to be in a zone of general ground-water discharge whereas areas inland from the Lake appear to be in a general area of recharge (Table 7).

Secondary porosities developed in the upper part of the bedrock likely constitute the major source for ground-water storage in the bedrock. The contributing thickness of bedrock to significant ground-water flow was estimated to be 50 feet. The extent of granular deposits in the overburden, which are the most productive materials for ground water, were delineated for the study area (Maps 6 to 9, inclusive).

Permeabilities of the overburden materials and the bedrock were computed using the modified, non-equilibrium well formula and specific-capacity data (Table 9). Permeabilities derived from the specific-capacity data are larger by approximately a factor of three than those permeabilities computed from the modified, non-equilibrium well formula. Water wells in the overburden are more productive than wells completed in the bedrock (Figure 4) with overburden wells having a specific-capacity range of 0.8 to 5.0 Igpm per foot of drawdown and bedrock wells a specific-capacity range of 0.07 to 0.7 Igpm per foot of drawdown.

Using permeability values derived from short-term pumping tests, an average transmissibility of 930 Igpd per foot was computed for materials within one mile of the present Lake Ontario shore in the study area. The mean overburden thickness penetrated by these wells was found to be 36 feet. Ground-water inflow to Lake Ontario, within the study area, was estimated to be 0.092 cfs per mile length of shoreline. A basic value of 3.2 cfs was estimated for direct ground-water discharge to Lake Ontario for the hydrogeologic region extending from the Humber River to the City of Oshawa along the north shore of Lake Ontario. An additional 1.8 cfs of ground-water discharge to Lake Ontario may be occurring along a 9-mile stretch of the comparatively high Scarborough Bluffs, west of the study area in the Borough of Scarborough.

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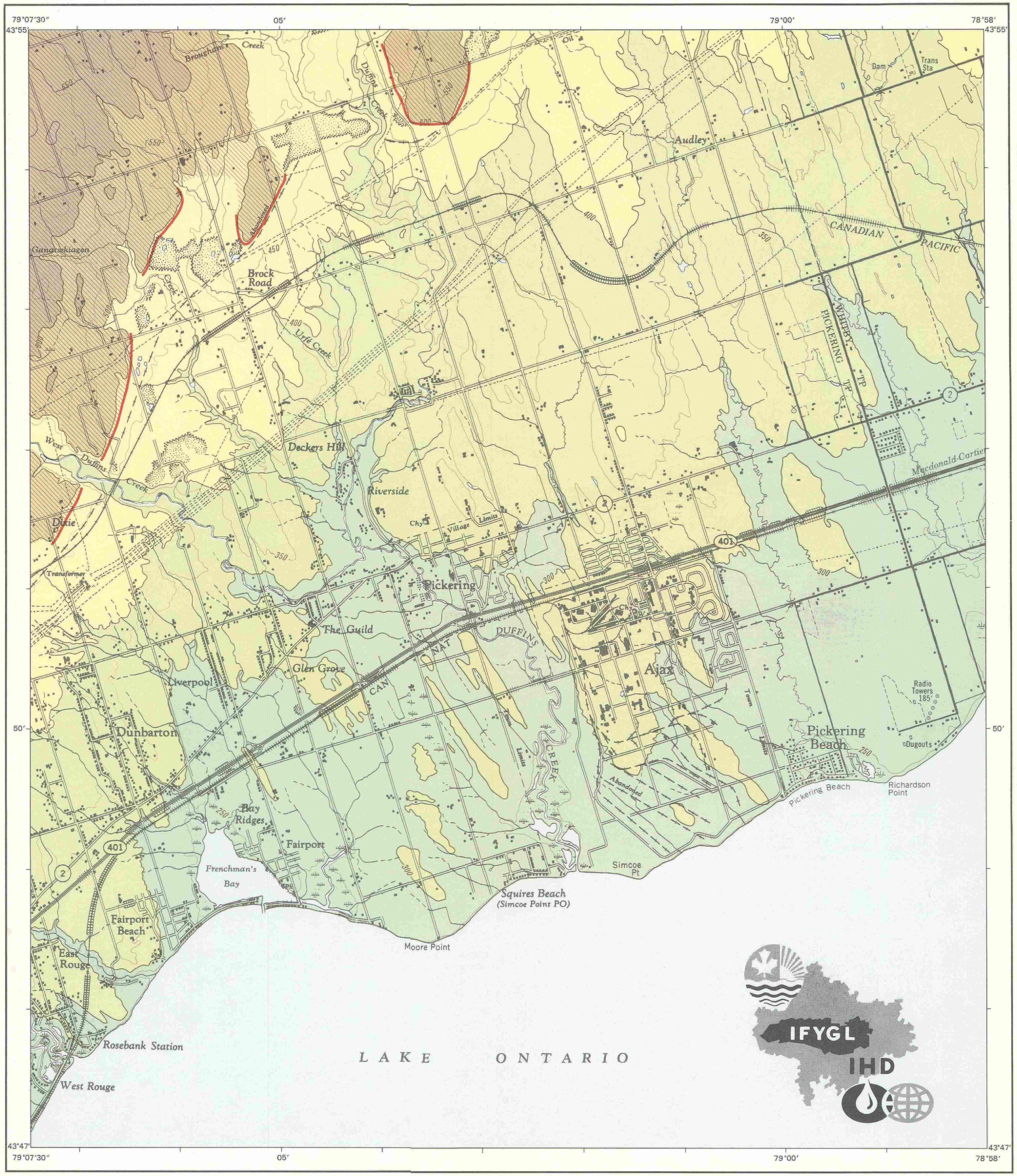

Transverse Mercator Projection

LEGEND

PHYSIOGRAPHIC REGIONS

- South Slope
- Iroquois Plain

ELEVATION RANGES

- above 700 feet
- 600-700 feet
- 500-600 feet
- 400-500 feet
- 300-400 feet
- Below 300 feet

SYMBOLS

- Lake Iroquois shoreline
- 350 Topographic contour, interval 50 feet

SOURCES OF INFORMATION

Data compiled by R. C. Ostry, 1974.

References:

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Hewitt, D.F., 1969, Industrial mineral resources sheet, Markham-Newmarket area; Ont. Dept. Mines, Map 2124.

Cartography by V. Roberts, 1974.

Base map derived from 1:50,000 map sheets 30M/14E and 30M/15 of the National Topographic Series.

To accompany Water Resources Report 5c

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

DUFFINS CREEK AREA

MAP 1

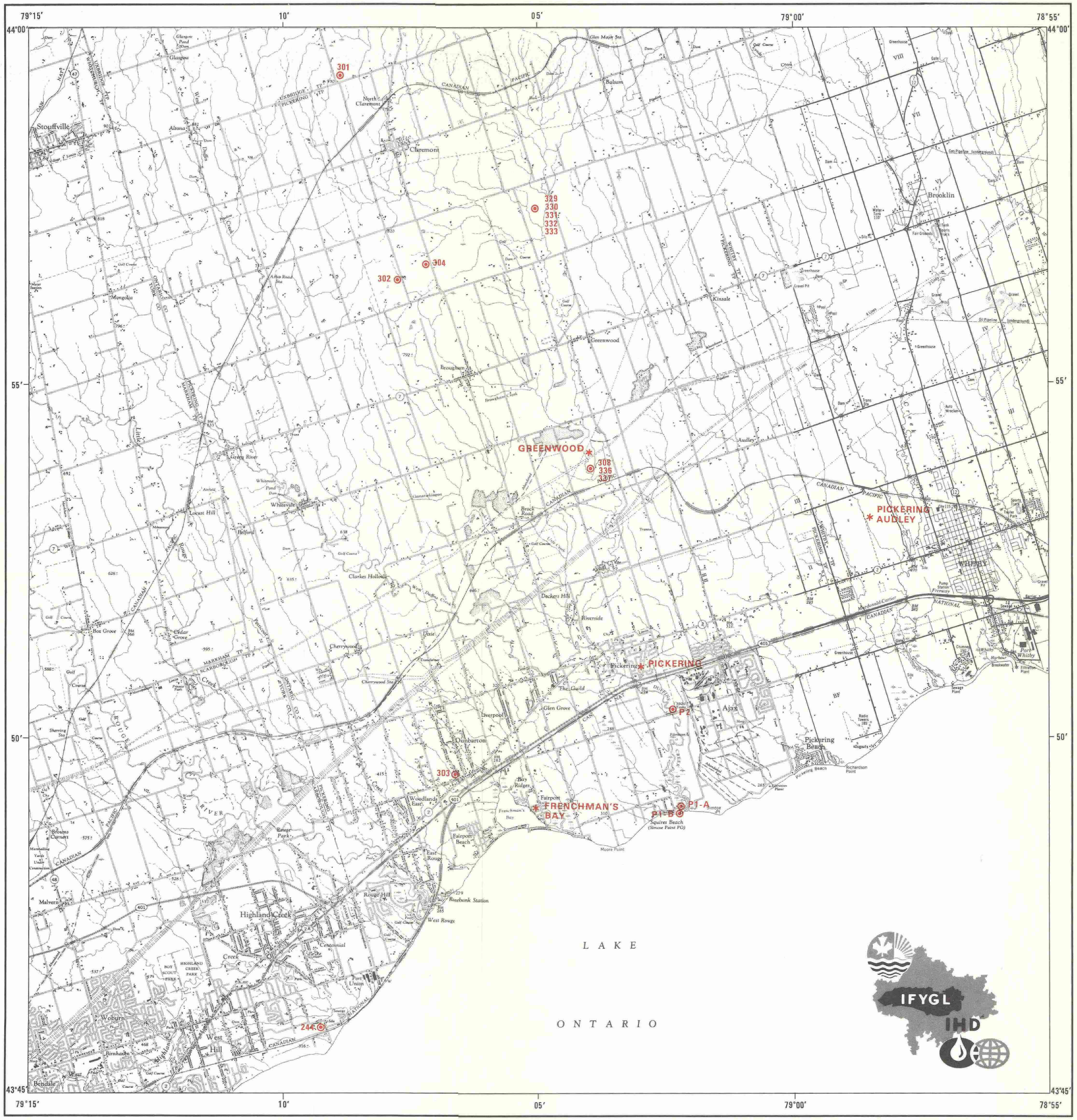
PHYSIOGRAPHIC REGIONS

Scale 1:50,000

1 inch equals 0.79 miles

0 ½ 1 2
Miles

0 ½ 1 2
Kilometres



SYMBOLS

*	Meteorological station
⊙ 301	Observation well

SOURCES OF INFORMATION

Data compiled by R. C. Ostry, 1974.

Reference:

Atmospheric Environment Services (unpublished), location of meteorologic stations.

Cartography by T. Gammage, 1975

To accompany Water Resources Report 5c

Ontario

MINISTRY OF THE ENVIRONMENT

Water Resources Branch

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

DUFFINS CREEK AREA

MAP 1a

METEOROLOGIC STATIONS AND OBSERVATION WELLS

Scale 1:100,000

1 inch equals 1.58 miles

0 1 2 4
Miles

0 1 2 4
Kilometres

MAP 4722-1a

9693600009272